Simultaneous optimisation of the nutritional quality and environmental sustainability of diets

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CHAPTER 5

Defining a nutritionally healthy, environmentally friendly, and culturally acceptable Low Lands Diet

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ABSTRACT[19]

Purpose: To demonstrate that linear programming can support to define nutritionally healthy, environmentally friendly and culturally acceptable diets, using the Low Lands as an illustrative example.
Methods: Our study quantifies the historical Dutch diet of 75 years ago, based on a cultural history research. We calculate the greenhouse gas emissions (GHGE) and land use (LU) of this diet, using actual life cycle assessment (LCA) data for the 206 most consumed products, and the Health Score, based on ten nutritional characteristics. In order to meet the current requirements, we optimize this diet for adult males using linear programming. We compare the diet with the present Dutch, Mediterranean and New Nordic Diet.
Results: An optimized Low Lands Diet has the same healthy nutritional characteristics (Health Score 123) as the Mediterranean Diet (122), and results in a lower environmental impact than the Mediterranean and New Nordic Diet (higher Combined GHGE-LU Score: 121 versus 90 and 91). GHGE are 2.60 kg CO_2eq per day and LU 2.86 m^2*year.
Conclusions: Through applying the method of linear programming it is possible to calculate an optimal diet for the Low Lands with a short cultural distance, that is as healthy as and more sustainable than a transition to more foreign European diets.

Keywords: greenhouse gas emissions, historical Dutch diet, New Nordic Diet, linear programming, Mediterranean diet

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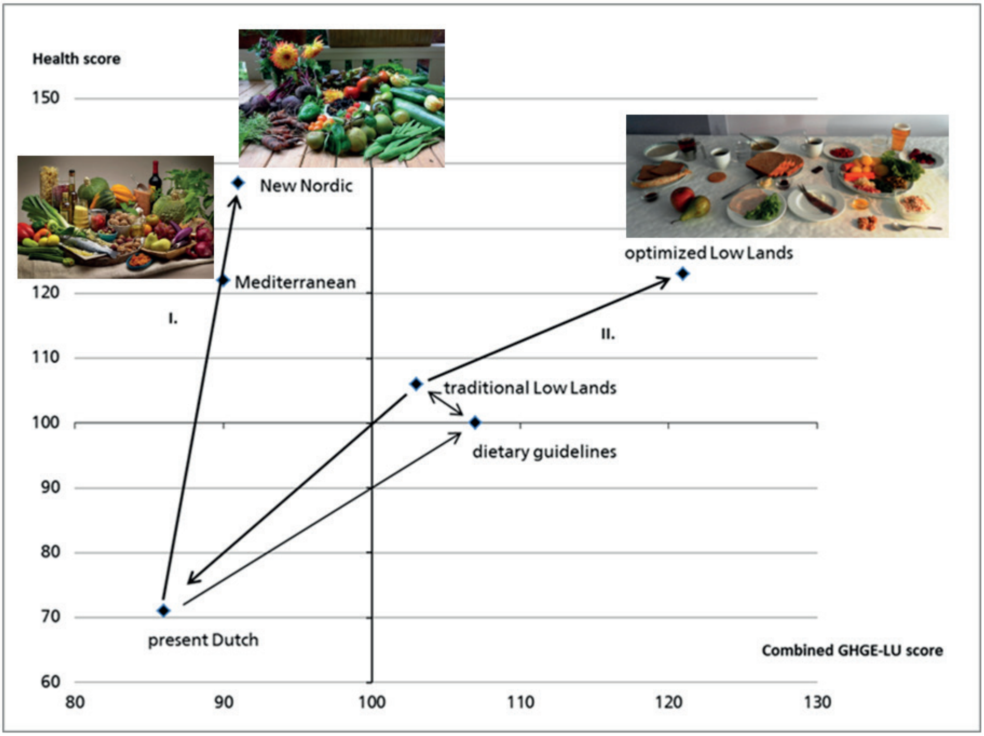

Figure 5.1: Graphical summary. An optimized Low Lands Diet has the same healthy nutritional characteristics (expressed as Health Score) as the Mediterranean Diet, and results in a lower environmental impact (higher Combined GHGE-LU Score) than the Mediterranean Diet and New Nordic Diet. This diet is assumed easier to achieve (Arrow II. versus arrow I.). On the X-axis the Combined GHGE-LU Score and on the Y-axis the Health Score.

5.1 Introduction

The present Dutch diet is not in line with the dietary guidelines (Health Council, 2006, WHO, 2003). Regarding the health impact, the diet has an unfavorable fatty acid composition, which increases the risk of cardiovascular diseases. Besides, only 5% of the Dutch population adheres to the recommended fatty acid composition through fish consumption. Insufficient consumption of fruit and vegetables increases the risk of coronary heart diseases, stroke and some forms of cancer (lung, breast and stomach cancer) (van Kreijl et al., 2006). The increased intake of energy-dense foods that are high in fat has resulted in a worldwide doubling of obesity since 1980. In the Netherlands 30% of the population aged 4 years and older are moderately overweight. Another 10% has severe overweight (obesity) (CBS, 2012). Overweight and obesity are major risk factors for a number of chronic diseases, including diabetes, cardiovascular diseases, and cancer. The unfavorable dietary composition contributes approximately twice as much to the total mortality as overweight: 10% versus 5% of the annual deaths in the Netherlands (van Kreijl et al., 2006).

Current trends in food production and consumption are considered unsustainable. For example, approximately one-third of human contributions to greenhouse gas emissions (GHGE) and land use (LU) is related to our diet and the food chain (Vringer et al., 2010). The average Dutch diet is less sustainable, in terms of GHGE and LU, than eating according to the Dutch dietary guidelines (van Dooren et al., 2014).

To reach more sustainable diets, policy makers are exploring the possibilities to develop guidelines for healthy diets that are also low in environmental impacts (Health Council, 2011). These guidelines are still qualitative and quite general. There is increasing evidence that nutritionally balanced diets can be compatible with environmental goals (Bajzelj et al., 2014, Tilman and Clark, 2014, Gunther et al., 2010).

In theory it is possible by applying linear programming to define an optimal diet, according to criteria both for health and environmental impact, using LCA data (van Dooren et al., 2015). However, such an optimized diet may have difficulties being broadly accepted by consumers.

Another approach is evaluating existing diets, such as the Mediterranean diet (MD), by scenario studies (van Dooren et al., 2014). This diet was built on the experience gained by scientists who recently explored and defined the Mediterranean diet (Bach-Faig et al., 2011, Garnett, 2006, Fidanza and Alberti, 2005). Epidemiological evidence suggests that a traditional MD may be beneficial to health (Keys, 1980). The term *Mediterranean Diet* originated from the 1960s when studies suggested that people living in Crete and South Italy were having a lower incidence of coronary heart disease (Keys, 1970). The new Scientific Report from the Dietary Guidelines Advisory Committee (DGAC, 2015) concludes that a sustainable pattern of eating can be achieved through a variety of dietary patterns, including the Healthy Mediterranean-style Pattern, that is aligned with lower environmental impacts and provides options that can be adopted by the US population. Is such an adaptation also advisable to other countries or are there smarter solutions possible?

Both gastronomists and nutritionists are beginning to believe that there is a shared route to creating regional diets and an opportunity to develop a healthy diet that bridges gastronomy, health and sustainability (Mithril et al., 2012). The traditional diets of Nordic countries have lately been advocated as healthy alternatives to the Mediterranean-like diets (Bere and Brug, 2009, Mithril et al., 2012). The healthy Nordic diet is in detail explored and described as the *New Nordic Diet* (NND) (Bere and Brug, 2009, Bere and Brug, 2010, Meier and Christen, 2013, Hahnemann, 2010, Mithril et al., 2012, Mithril et al., 2013, Uusitupa et al., 2013, Meier and Christen, 2013).

In the Dutch context, eating according to the Dutch dietary guidelines is a more obvious way to get to a healthier and a lower environmental impact than the present Dutch diet (Health Council, 2011). However, further improvements in Health Scores, GHGE, and LU are within reach, as concluded in Van Dooren et al. (2014). Is it possible to seek sustainable, dietary solutions that fit better into the historical and cultural context, and climate of the Netherlands, than the MD or NND? Does the Nordic approach by shifting to the local, traditional diet, the so called Low Lands Diet[20], result in the best scenario? Our hypothesis is that, through applying the method of linear programming, an optimal diet for the Low Lands of Europe can be calculated, that is even healthier and more sustainable than advising MD, NND or a traditional LLD.

The aim of this paper is to demonstrate that linear programming can facilitate the definition of nutritionally healthy, environmentally friendly and culturally acceptable diets, using the Low Lands as an illustrative example.

5.2 METHODS: APPROACH

In order to substantiate our hypothesis and reach our aim, we first describe our method to quantify the nutritional health (section 5.2.1) and environmental impact of different diets (5.2.2). To calculate the environmental impact, we need the GHGE and LU data of food products. Reliable data are sourced; using actual Life Cycle Assessments for the 206 most consumed Dutch products (5.2.3). We apply this calculation methods to diets found in literature (5.2.4). The reference group for this study is adult men aged 31-50 years. This is the biggest subgroup (2.3 million people) and most representative for the adult population. Men have the highest consumption of calories and have the highest environmental impact and reduction potential.

5.2.1 CALCULATING THE HEALTH SCORE

The health benefits and impacts of diets are highly complex, under continual debate and not easy to quantify. Insight in and impact of different indicators are relative and change over time. Fortunately, different health organizations, such as WHO (2003), World Cancer Research Fund, RIVM, and the Dutch Health Council (2006) have been using more or less the same indicators. The existing concept of the US Healthy Eating Index (Kennedy et al., 1995) to quantify overall diet quality is useful, but not directly applicable to Europe due to differences in cultural habits (serving sizes) and nutritional guidelines. Therefore, we developed a related score relevant to the European context. This Health Score is described elsewhere (van Dooren et al., 2014). The Dutch Health Council (2006) has translated and quantified the ten indicators towards a recommended intake by the Dutch population used as numerators and denominators. These indicators reflect preventive factors for different

[20] *Low Lands refer to the Rhine-Meuse delta, mainly characterized by fertile flat land at North Sea level, a temperate climate, and a sober, tolerant, former Calvinist, Dutch speaking culture. This study focusses on Dutch data.*

food-related diseases, such as obesity, heart disease and cancer. The ten nutritional characteristics are equally weighted by summing them and dividing the sum by 10. We calculate the scores of diets, based on the ten indicators, with the following formula: Eq. 1 (en% = percentage of caloric intake).

$$\text{Health Score} = \left(\frac{\text{g vegetables}}{200\text{g}} + \frac{\text{g fruits}}{200\text{g}} + \frac{\text{g fiber}}{30\text{g}} + \frac{\text{g fish}}{37\text{g}} + \frac{6\text{g}}{\text{g salt}} + \frac{30\text{en\%}}{\text{en\% total fat}} + \frac{10\text{en\%}}{\text{en\% sat. fat}} + \frac{1\text{en\%}}{\text{en\% trans fat}} + \frac{10\text{en\%}}{\text{en\% free sugars}} + \frac{2500\text{kcal}}{\text{kcal energy}} \right) \text{ x } 100 \Big/ 10$$

Eq. 1 (based on Van Dooren et al., 2014)

5.2.2 Calculating the Combined GHGE-LU Score

In 2010 the FAO agreed upon a definition for sustainable diets (FAO, 2010a): 'Sustainable Diets are those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations.' *Low environmental impacts* —as part of the definition of sustainable diets— need to be quantified using different parameters. Energy use and GHGE can be considered good proxies for this total environmental impact (Dutilh and Kramer, 2000, Laurent et al., 2010, Garnett, 2011). GHGE is the most accepted parameter in this kind of studies: approximately half of the studies assessing environmental impacts of diet patterns examined climate impact as GHGE. Approaches to assess capacity of land use are being developed and tested (Auestad and Fulgoni, 2015). LU and land use change are good proxies for loss of biodiversity (Pereira et al., 2010). In the score, we therefore used GHGE and LU as indicators to quantify —in relative terms— the environmental impact of the diets, because together they cover at least the top four of the impacts identified by Rockström et al. (2009) as discussed by Aiking (2014). Our Combined GHGE-LU Score is defined in an earlier study (phrased as *Sustainability Score* in Van Dooren et al. 2014). The European Commission set a 2020 goal of a 20% GHGE reduction for all sectors (compared to 1990). We applied the goal in the food chain as a reference value, although it is a political, arbitrary choice. The GHGE of the Dutch diet in the 1990s was 4.09 kg CO_2eq/day; the 2020 goal is 20% lower or 3.27 kg CO_2eq/day. This level was allocated a score of 100.

Most LU for food production (79%) is outside the Netherlands. Land used for the Dutch ecological footprint was mainly located in OECD countries (about 52%, including the Netherlands), about 48% in upcoming economies: Brazil (15%) and South-East Asia (9%), e.g. soy and palm oil (CBS et al., 2013). This LU of arable land of 0.32 ha is 38% above the available 0.2 ha per person worldwide, according to the FAO (Bruinsma, 2009). Assumed that the arable area per capita worldwide will remain the same, the LU per person has to decrease by 38%. We used as a reference a 38% reduction in the food chain applied for LU. From 5.34 m^2*year/day (the LU of the 1990s Dutch diet) to 3.32 m^2*year/day is a 38%

reduction. This value was indicated as 100. The Combined GHGE-LU Score was defined as the average of the GHGEs and LU score per diet. The score was calculated with the following formula: Eq. 2.

$$\text{Combined GHGE} - \text{LU Score} = \frac{\left(\frac{3.27\ \text{kg}}{\text{kg } CO_2 \text{eq GHGE}} + \frac{3.32\ \text{m}^2 * \text{year}}{\text{m}^2 * \text{year LU}}\right) \times 100}{2}$$

Eq. 2 based on (van Dooren et al. 2014)

5.2.3 Life Cycle Assessment of food products

Our calculation of GHGE and LU for the most consumed products in the diets is based on Life Cycle Assessment (BSI, 2008, Benziger et al., 2016, JRC, 2010). Wegener Sleeswijk et al. (1996) published the first set of guidelines on methodological topics for LCAs of agricultural products in the Netherlands. A specific PAS2050 guidance for horticultural products was developed in 2012 (BSI, 2012) and in 2013 the Environmental Assessment of Food and Drink Protocol (ENVIFOOD) was published by the European Food Sustainable Consumption and Production Round Table (FoodSCP, 2012). The LCA methodology for agricultural products we use is in line with these protocols and described in ‘The Agri-footprint method; Methodological LCA framework, assumptions and applied data, Version 1.0’ (Blonk et al., 2011). The life cycle boundary is from raw materials acquisition and natural resources to final disposal, including food waste, and some estimate of energy use for cooking and preparation at home. The data are based on food products harvested, processed or imported in the Netherlands in 2011, if necessary updated in 2014. Most of them are available in the Agri-Footprint database (www.agri-footprint.com; Durlinger et al., 2014). LCAs of food products are mostly expressed per mass unit (kg), although other units are defendable, but no consistent solution has emerged (Heller et al., 2013). This study has daily intake for male adults as a functional unit. In LCAs of agricultural products, the main contributors to the end score are GHGE, LU, and fossil energy use, together responsible for almost 90% of the impacts within the food chain in the Netherlands (Sevenster et al., 2010). Two of these are covered. In the scope of this study, it was not possible to carry out an extensive assessment to determine standard deviations for the parameters. LCA experts assume a general uncertainty of 10% to 20% in the results (Blonk et al., 2011).

5.2.4 Literature research

Using literature research, we define European examples of diets which are mentioned as both nutritionally healthy and low in environmental impact. We focus on recent publications exploring the Mediterranean and New Nordic Diets. In order to compare these diets with the Low Lands Diet, we quantify also the historical Dutch diet of about 75 years ago (1900-1940), based on cultural history research, questionnaires and consumption statistics (Jobse-Van Putten, 1995, Van Otterloo, 1990).

5.2.5 LINEAR PROGRAMMING

Although it cannot be assumed that a healthy diet will always have lower GHGE (Macdiarmid, 2013), we do expect that linear programming will make it possible to find a diet with lower impacts than those diets found in literature.[21] This is confirmed in a recent paper of our group (van Dooren et al., 2015). Several studies in other countries —for instance UK, France and New Zealand— have also successfully used linear programming for diet optimization.

Linear programming is a mathematical technique that allows the generation of optimal solutions (Dantzig and Thapa, 1997). The method we use for linear programming in this study is based on to the one used by (Macdiarmid et al., 2012). This mathematical method optimizes an outcome which is a linear function of several variables that can be controlled (e.g. the amount of food eaten), while subject to a number of constraints (e.g. dietary requirements) (Macdiarmid et al., 2011). The method is improved by adding more nutritional constraints and a proxy for popularity. The linear programming algorithm minimizes the absolute changes in terms of portions to the present diet (see also Maillot et al., 2010b); weighted by a proxy of popularity, while satisfying a number of constraints. Due to the weighting, it evaluates positive deviations from the present diet differently from negative deviations. More specifically, the optimization weights are constructed from the normalized value of the total food consumption based on weight (n=206, based on Van Rossum et al., 2011) for male adults (31-50y). The total GHGE of a diet consisting of amounts of n food products $(x_1, x_2, ..., x_n)$ and the associated GHGE of each food product per unit weight ($GHGE_i$) is as follows: Eq. 3.

$$GHGE_{diet} = \sum_{i=1}^{n} x_i GHGE_i \quad \textbf{Eq. 3}$$

In addition, the diet has to satisfy the energy and nutrient requirements (constraints) and, when applicable, an upper limit for total GHGE. Satisfying the energy and nutrient requirements equals a Health Score of 100. Each constraint can be denoted as $b_1, b_2, ..., b_m$, and with each food product i contributing a_{ij} per unit weight to requirement j, a set of j dietary constraints was established such that: Eq. 4.

$$b_j \geq \sum_{i=1}^{m} a_{ij} x_i \quad \textbf{Eq. 4}$$

Optimization is done by linear programming using the newly developed Optimeal® software of Blonk Consultants and the Netherlands Nutrition Centre, which runs with

[21] *Mentioned as Dietary Regimens in the summary.*

MATLAB Compiler 7.16 and Microsoft Access Runtime. During optimization we use 33 nutrients and GHGE as constraints. Adequate intake levels and dietary guidelines of 33 nutrients are given by the Netherlands Nutrition Centre (2008) and the Health Council of the Netherlands (Health Council, 2001, Health Council, 2006, Health Council, 2009) as the first constraint (Table 5.1). Secondly, the upper boundary for climate impact (GHGE) is set to 2.60 kg CO_2eq/day. This represents a 20% reduction of the present GHGE of the Dutch diet (males 3.52 kg CO_2eq/day; Marinussen et al., 2012), as a feasible target. The optimization tool Optimeal® is proven to be helpful in detecting less restricting diets, closest to a given diet, within the constraints (Tyszler et al., 2016).

Table 5.1: Nutritional constraints with lower and upper limits for male adults (31-50 years) used in the optimization of the diet.

	Nutrient	Unit	Lower	Upper
1	energy	kcal	2360	2640
		KJ	9874	11046
2	protein	g	59	156
3	carbohydrates	g	250	438
4	fats	g	55.6	97.2
5	saturated fatty acids	g	-	27.8
6	trans fatty acids	g	-	2.8
7	polyunsaturated fatty acids	g	-	33.3
8	cholesterol	mg	-	300
9	dietary fiber	g	40	-
10	alcohol	g	-	20
11	water	g	2500	4000
12	sodium	mg	-	2400
13	potassium	mg	3500	-
14	calcium	mg	1000	2500
15	phosphorus	mg	700	-
16	magnesium	mg	350	600
17	iron	mg	9	-
18	copper	mg	1.5	-
19	selenium	µg	50	-
20	zinc	mg	10	-
21	iodine	µg	150	600

22	retinol act eq	µg	1000	3000
23	vitamin D	µg	2.5	50
24	vitamin E	mg	11.8	-
25	vitamin B1	mg	1.1	-
26	vitamin B2	mg	1.5	-
27	vitamin B6	mg	1.5	25
28	folic acid eq	µg	300	1000
29	vitamin B12	µg	2.8	-
30	vitamin C	mg	70	-
31	omega-3 fatty acids	mg	450	1000
32	vegetables	g	200	500
33	fruits	g	200	500

5.3 Results

5.3.1 Defining the Mediterranean Diet (MD)

The MD has been the subject of many studies (Trichopoulou et al., 2005) and we have previously studied this diet (van Dooren et al., 2014). The MD is characterized by a high intake of vegetables, pulses, fruits, and cereals (in the past largely unrefined); a moderate to high intake of fish; a low intake of saturated lipids, but high intake of unsaturated lipids, particularly olive oil; a low to moderate intake of dairy products, mostly cheese and yogurt; a low intake of meat; and a modest intake of alcohol, mostly as wine (Willett et al., 1995). The best quantitative description of this historical diet is probably published by Fidanza and Alberti (2005).

Harvard Medical School further translated the dietary pattern into a more Western, culturally acceptable, diet with concrete recommendations (Willett, 2001) and Willett published together with Oldways in 2009 the Mediterranean Diet Pyramid (www.oldwayspt.org). A consensus meeting recently updated the Mediterranean diet pyramid (Bach-Faig et al., 2011). Buchner et al. (2010) published the Double Pyramid and compared the ecological footprint of foods with their health-related position in the pyramid. They concluded that foods that are recommended for health reasons generally have lower environmental impacts as well. By the same token, foods with lower recommendations are those with a higher environmental impact. In an earlier climate diet study, the Mediterranean diet according to Harvard was also evaluated (Stehfest et al., 2009). In Table 5.2 we compare three ways to quantify the MD. The right-hand column has been used for this study.

The Health Score of the MD is 122, which is higher than the recommended guidelines (Table 5.4), and the Combined GHGE-LU Score for males (90) is below the formulated goals (=100). The question is: Is this healthy, culturally accepted Southern European diet transferrable to Northern European areas?

Table 5.2: Quantification of the Mediterranean Diet.

(Fidanza and Alberti 2005)	***(Bach-Faig et al. 2011)***	***(van Dooren et al. 2014)***
(% of energy)	(servings (s))	(grams per day)
cereals (48%–52% of energy)	1-2 s pref. wholegrain every meal	210 g wholegrain bread
		100 g grain products (pasta)
extra virgin olive oil (14.5%–16.6%)	olive oil every meal	45 g vegetable oils
vegetables (5%–7%)	>= 2 s every meal	300 g mainly fresh vegetables
	potatoes <= 3s weekly	25 g potatoes
pulses (4.4%–6.6%)	>= 2 s weekly	75 g pulses
fruit (2.0%–2.6%)	1-2 s every meal	250 g fruits
fish (1.6%–2.0%)	>= 2 s fish/seafood weekly	fish/seafood 2 times a week*
red wine (4.2%–6.0%)	wine in moderation	150 ml red wine (1 glass)
	1-2 s olives, nuts, seeds daily	
	herbs, spices, garlic, onions daily	
meat (2.6%–4.0%)	< 2 s red meat weekly	beef or pork once a week *
	<= 1 s processed meat weekly	
	2 s white meat weekly	chicken once a week *
milk and dairy products (1.3%–1.8%)	2 s dairy daily (pref. low fat)	300 ml milk or dairy products 15 g cheese
eggs (0.8%–1.4%)	2-4 s weekly	3 eggs a week*
animal fats (1.0%–2.0%)		
	<= 2 s sweets weekly	200 kcal non-basic products

**100 g animal products total*

5.3.2 Defining the New Nordic Diet (NND)

We find an answer as we look into the Nordic Diet. Although the Mediterranean cuisine is also popular in Western European countries, food patterns differ significantly across

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different countries (de Boer et al., 2006). We came across a Scandinavian variant of the Mediterranean diet, the NND. This Northern European diet consists of many local Scandinavian traditional products such as fish, berries, cabbage, rapeseed oil, rye, oats and game (Hahnemann, 2010). Dietary components with substantial evidence of health-promoting properties that are part of the Nordic Nutritional Recommendations 2012 (Norden, 2014) are naturally included in the NND, e.g. fruits, vegetables, potatoes, whole grains, nuts, fish and shellfish (Mithril et al., 2012). The diet is quantified in table 5.3. The *New* diet is also based on long local traditions; in the Middle Ages foods such as fresh herbs, legumes, cabbage and root vegetables played a major role in the Nordic Diet, but their use has decreased significantly over recent decades (Mithril et al., 2012).

The NND can be described by overall guidelines: a) more calories from plant foods and fewer from meat; b) more foods from the sea and lakes; and c) more foods from the wild countryside (Mithril et al., 2012). According to studies by Bere and Brug (2009, 2010), this diet has a positive health impact, and a low environmental impact, similar to the MD. Bere and Brug advise moderation of beverages such as coffee, soft drinks, fruit juice and alcohol, and fatty and sweet *extras* in between meals in order to improve the scores.

Our calculation results in a higher Health Score of 134 for the NND and results in the same Combined GHGE-LU Score of 91 (Table 5.4), compared to the MD. It does not meet the formulated sustainability goals. Mithril et al. (2012) concluded that the principles and guidelines of the NND could be applied in any region. In the next section we will look if an application to the Low Lands is feasible and if this diet has a higher Combined GHGE-LU Score.

5.3.3 Defining the Low Lands Diet (LLD)

Although the Scandinavian culture stands closer to the Low Lands than the Mediterranean, it still differs significantly. The challenge is to define and investigate a LLD, with qualities and Health Score comparable to those of the MD or NND, but with a higher Combined GHGE-LU Score. A similar health effect as the NND can be expected in the Low Lands with a traditional, predominantly plant-based diet (semi-vegetarian), also with lots of fresh and regional vegetables, fruits and whole grains (bread, pancakes, porridge), a local vegetable oil, supplemented with limited amounts of fish, eggs, meat, and milk.

The Dutch diet from the beginning of the 20th century (1900-1940) is well described by Jobse-Van Putte (1995) and fits into this description. Research was done by interviewing older people from different areas and analyzing official documents and statistics. There are no quantitative diet surveys available prior to the 1960s. Other sources confirm the findings from Jobse-Van Putte (1995), such as Knibbe (2001) and Van Otterloo (1990). Due to an open trading economy and immigration, an early adaption of coffee, tea, rice and spices took place (Albala, 2003, Biesbroek et al., 2014, Jobse-Van Putten, 1995, Schösler et al., 2015).

Table 5.3: Quantification of the New Nordic Diet according to Uusitupa and Mithril (en% = % of caloric intake).

Healthy Nordic Diet *(Uusitupa et al., 2013)*	**New Nordic Diet (grams per day)** *(Mithril et al., 2012)*
500 g/week wholegrain pasta and rice (25en% whole grains)	
210 g bread/d (6 slices)	275 g wholegrain bread and cereals
>50% as rye, barley or oat	
150-200 g/d berries	75 g berries
175 g/d fruits	250 g fruits
175 g/d vegetables	150 g root vegetables
	30 g cabbages, 240 g other vegetables
	45 g legumes
	175 g potatoes
rapeseed or sunflower oil (2/3 unsaturated fats)	15 g rapeseed oil
soy oil based margarines	10 g butter
nuts and seeds unsalted	30 g nuts and seeds
	6 g wild plants, mushrooms, herbs
2 portions/d low-fat milk and cheese	450 g low-fat milk (+50 g other dairy)
	25 g cheese
3 portions fish/week (2 fatty)	43 g fish and shellfish (5 g seaweed)
white meat, poultry, game	100 g meat (4 g game)
	25 g eggs (1/2)
50 g/d apple juice	
	75 g extras
	15 g sugar
	1000 g coffee, tea, water (600 g)

A general, typical LLD is described in Table 5.5. The availability of statistics between 1930 and 1950 is low, but we managed to find data on the consumption of bread, pulses, potatoes, milk, meat, and fish (CBS, 2001). Due to the low-income situation, no food was wasted (Jobse-Van Putten, 1995). This LLD is plant based: it includes a maximum of 30 energy% deriving from an animal origin. In the countryside most of the people were self-sufficient. They had a vegetable garden and an acre with rye or other grains and a pig. Once a year the pig was slaughtered and the pork and grease were consumed until lent. Bread was baked once for a whole week. Farmers in the lower grassland —clay and moor— areas (river sides, lake sides and coastal area) owned cows. One cow was available per four inhabitants. The butter was mostly sold and buttermilk was for own use. Porridge cars went by homes on a daily basis to sell porridge made of buttermilk and barley. People living in the eastern sand areas consumed a more rye based diet. In the cities more wheat was consumed. Typical for the culture is the cooking of hot meals based on potatoes and seasonal vegetables in one pot (‘*stamppot*’) and for several days. Thanks to the trade connections, rice, spices, coffee and tea were common at an early stage, influenced by trade and migrant cultures. Fresh fish was only available in coastal zones; freshwater fish consumption dropped in the eighteenth century, due to overfishing. Beef, poultry and game were not regularly on the menu.

The Health Score of 106 and the Combined GHGE-LU Score of 103 of the LLD (Table 5.4) are comparable to the recommended guidelines (Health Council, 2006), but the Health Score is lower and the Combined GHGE-LU Score higher than the MD and NND. In other words, the diet is more sustainable but less healthy. Both scores of the traditional LLD are higher than the present diet. Below we will look for an interactive method to improve the GHGE and LU scores, and the suboptimal intake of vegetables, fruits, fiber and fish and to lower the salt consumption in the LLD.

5.3.4 An optimized LLD

Optimization of the historical LLD resulted in an increased content of vegetables, fruits and dietary fibers, and a decrease in salt. Table 5.5 shows the result of the historical research into the LLD and the results of optimization by linear programming. Due to the constraints and penalty rules, the optimization resulted in a diet which is both palatable and in line with the traditional diet. Various elements of this diet are in use at the moment, for instance a high consumption of potatoes and wheat bread compared to other European countries, the preference for cabbage, root vegetables and local fruits (apple, pear), the level of milk consumption and the habits of drinking coffee, tea and beer.

Table 5.4 (next page): GHGE, LU, Combined GHGE-LU Score, daily nutritional characteristics, and Health Score of the present Dutch, Mediterranean, New Nordic, historical Low Lands, and optimized Low Lands diets (males 31-50 years). The 10 nutritional characteristics are the elements of the Heath Score (van Dooren et al., 2014).

		dietary guidelines	present Dutch	Mediterranean	New Nordic	historical Low Lands	optimized Low Lands
1	GHGE (kg CO_2-eq)	3.07	3.52	3.24	3.82	3.24	**2.60***
2	Land use (m^2*year)	3.08	4.15	4.15	3.42	3.18	**2.86**
	Combined GHGE-LU Score	107	86	90	91	103	**121**
1	Vegetables (grams)	200	119	300	**420**	179	215
2	Fruits (grams)	200	82	250	**350**	145	277
3	Fatty acids (en%)	25	34.5	20.5	21.5	25.2	24.2
4	Saturated fatty acids (en%)	10	12.7	6.9	**6.7**	8.4	7.3
5	Trans-fats (en%)	1	1	0.5	0.4	0.3	**0.2**
6	Free/added sugars (en%)	10	10	7.6	9.4	**3.5**	4.5
7	Dietary fiber (grams)	40	23	33	**47**	37	40
8	Salt (grams)	6	7.9	5	5	**7.6**	5.8
9	Fish (grams)	37	12	37	**43**	25	37
10	Energy in diet (kcal)	2500	2647	2503	2560	2651	**2500**
	Health Score	100	71	122	**137**	106	123

best scores in* ***bold*

05

Table 5.5: Quantification of the daily, historical and optimized Low Lands Diets for male adults, by historical research and linear programming. As reference diets are added: the present Dutch diet (van Rossum et al., 2011) and the recommended diet in line with the dietary guidelines (Nutrition Centre, 2011).

	Present Dutch diet	Historical Low Lands diet	Optimized Low Lands diet	Recommended diet
Vegetables	116 g	180 g (leafy, roots, cabbages)	215 g (extra lettuce and kale)	200 g
Fruits	87 g	145 g (apple, pear, berries)	277 g (extra pear)	200 g
Legumes	3 g	18 g	51 g	*
Nuts	5 g		24 g	*
Fish	12 g	25 g	37 g (oily)	37 g*
Meat and meat products	112 g	55 g (pork, beef and chicken)	47 g (pork and chicken, 8 g beef)	67 g*
Total protein products	132 g	98 g	122 g	125 g*
Soups	55 ml	35 ml	35 ml	
Bread and grain products	222 g	210 g rye and wheat bread (6 slices)	210 g rye and wheat bread (6 slices)	245 g bread
		30 g rice and 10 g other grain products	10 g other grain products	
Potatoes	107 g	350 g	350 g	250 g (incl. rice & pasta)
Milk and dairy	306 ml	2 portions porridge incl. 250 ml buttermilk and 150 ml full fat milk	2 portions porridge incl. 325 ml skimmed milk and 150 ml full fat milk	450 ml
Cheese	20 g	20 g	no	30 g
Fats and oils	29 g	40 g butter, rapeseed oil, margarine	40 g butter, rapeseed oil, margarine	50 g
Non-alcoholic drinks	1621 ml	300 ml coffee, 250 ml tea	300 ml coffee, 250 ml tea, 300 ml water	1050 ml
Alcoholic drinks	216 ml	300 ml beer, 6 ml wine	300 ml beer	-
Extras	103 g	32 g (sugar, jam, chocolate, syrup, cake)	32 g (sugar, jam, chocolate, syrup, cake)	Max. 400 kcal

**meat+fish+eggs+legumes+nuts*

Furthermore, this optimization placed the LLD scores in between the Health Scores of the MD and NND, but resulted in the highest Combined GHGE-LU Score (i.e. lowest environmental impact, Table 5.4). GHGE are 2.60 kg CO_2eq per day and LU 2.86 m^2*year. The Health Score is 123 and the Combined GHGE-LU Score 121. The Combined GHGE-LU Scores (Table 5.4) of the Nordic, Mediterranean, traditional LLD and recommended dietary guideline are on the same level between 90 and 110. Only the optimized LLD is substantially higher. An unexpected result is that the Health Score of the optimized LLD is close to the high score of the NND. Both are higher than the MD, which is generally considered as very healthy. The optimization results in a diet within the 33 nutritional constraints and with low GHGE and LU (or high Combined GHGE-LU Score). Through applying the method of linear programming, it was possible to calculate an optimal diet for the Low Lands, that is, as healthy as and more sustainable than diets such as MD, NND or a traditional LLD.

5.3.5 OPERATIONALIZATION OF *CULTURAL ACCEPTABILITY*

The above section demonstrates that with linear programming it is possible to define a nutritionally healthy and environmentally friendly diet. The question remains if it is culturally acceptable. *Cultural acceptability* can be operationalized as the distance between the present Dutch diet and the advised or studied scenario diets. The distance in terms of Health Score is shown in Table 5.4 and Fig. 5.1. Distance between MD and present Dutch is 51 points, which is 22 extra above the dietary guidelines. This is comparable with the optimized LLD (52 points). The distance for the NND is bigger: 66 points. The distance for the traditional LLD is the smallest: 35 points, close to the minimum of 29. In other words; the cultural distance between LLD and present Dutch is much smaller than between NND and present, but the gain in sustainability terms is much bigger. By taking traditional LLD as starting point, instead of present Dutch, the distance to the Guidelines is small: 6 points. Table 5.4 demonstrates that the Health Score of the traditional LLD needs some improvements in terms of fruits, vegetables and fish consumption and reduction of salt. This is achieved by optimization, which results in an acceptable distance of 17 points.

Cultural acceptability can also be operationalized as the number and quantity of changes in the diet. Changes can be identified by comparing the Tables 5.2, 5.3, and 5.5, but they are not summarized in one number. Advising MD —for instance— results in a mayor shift from potatoes to pasta, increase in legumes, and changes in types of vegetables and dishes. Advising NND results in a major shift to wild sources of fruits and meat, fish and types of grain products. Advising LLD retains the types of foods, but results in major changes in quantities of potatoes and bread, which is in line with the recommended diet. All diets results in a lowering of meat consumption. The acceptability of the latter will be discussed in the discussion section.

To reach the optimized LLD compared to the traditional LLD, the consumption of (local and seasonal) fruits, vegetables and legumes has to increase. Nuts should be added to the diet. The consumption of fish and white meat should be increased and the intake of cheese and beef has to be reduced. The low level of beef and exclusion of cheese is in conflict with the current consumption levels. The used method of linear programming in itself results in the least as possible number of changes: in the total weekly diet only nine products were added, two products eliminated, and ten changed in portion size. The optimized LLD seems to be a cultural acceptable option, which amply meets the nutritional and environmental constraints.

5.4 Discussion

In this paper we were able to define a nutritionally healthy, environmentally friendly, and culturally acceptable Low Lands Diet. The historical quantification of the diet before 1940 is subject to uncertainties. Changes in the starting point will result in different optimal solutions. The qualities of the LLD are in line with the benefits of MD and LLD, based on the quality of historical diets from decades ago. In order to give relevant recommendations both historical, cultural patterns and present lifestyles (consumption and energy expenditure) have to be taken into account.

This study yields different scores when compared to the same diets in the 2014 paper (van Dooren et al., 2014), because this study is about men instead of women. We demonstrated that the MD is generally the health focus option with an increased Combined GHGE-LU Score. In contrast, this paper demonstrates that the NND is also a prototype regional diet taking health, food culture, palatability and the environment into account for Nordic countries. The principles and guidelines can indeed be applied in any region (Mithril et al., 2012). We demonstrated the feasibility to apply this to the Low Lands.

There is some research that confirms the health impact of the NND. Uusitupa et al. (2013) for instance investigated the effects of an isocaloric healthy Nordic diet on insulin sensitivity, lipid profile, blood pressure and inflammatory markers in people with metabolic syndrome. Uusitupa et al. concluded that a healthy NND improved lipid profile and had a beneficial effect on low-grade inflammation. In 2009, OPUS was launched as a comprehensive research project for optimal well-being, development and health of Danish children through a healthy NND. The preliminary results of the scientific research on the correlation between weight loss and the NND show that eating Nordic food is an effective way to curb obesity in the Danish population (Poulsen et al., 2014).

Although the NND has the highest Health Score, a higher Combined GHGE-LU Score can be found through optimization of the LLD. This study confirms that a local diet with higher scores is possible by taking a historical diet as the starting point, combined with optimization on health and sustainability parameters under current conditions. Taking historical LLD as the starting point is an advantage because consumer segmentation research indicates that 13% of the Dutch population still has a traditional consumption pattern and that another 22% has a somewhat modernized traditional pattern. Other segments consume at least a majority of the products in the LLD (Lampert, 2014). These

35% are at very short cultural '*distance'* and can apply an optimized LLD with small changes in consumption. In other words: Diets are improved by keeping as many products as possible from the starting point, and by adding products that are currently popular in order to create a culturally acceptable diet.

Therefore, it is not surprising that among adult men the current consumption of cereals including bread (222 g, see Table 5.5), dairy (306 g), fats (29 g), beer (185 ml) and coffee (480 ml) is better comparable to the LLD than to the MD. Some food habits remain unchanged for many centuries (de Boer et al., 2006). The stable bread consumption in Western Europe illustrates for example that culture is a strong predicting factor. It differs widely within the EU: the Dutch consumption is still high with 60 kg above the average of 50 kg/y, but lower than in Germany and Austria. Countries in Northern Europe (Nordic countries and the Netherlands) have —since decades— also the highest consumption per capita of liquid milk in the world, being twice as high as the average consumption in the EU (EFSA, 2015). Consumption of a part of the products changed over the last decades: the levels of potatoes, fruits and vegetables are lower, and meat, cheese and *extras* are higher (van Rossum et al., 2011). These levels are supposed to be hurdles in the consumer acceptance of a more healthy and sustainable LLD, but methodological the programming retains as many products as possible and if changes needed, recently popular, frequently consumed, products are favoured. Nevertheless, the optimized LLD is palatable in its preference for cabbages, root vegetables and local fruits, and habits of drinking coffee, tea, milk and beer. Cultural factors related to gender and ethnic diversity can play harmful and beneficial roles for achieving sustainability and health objectives (Schösler et al., 2015). The example of this study can be used to improve Health Scores and Combined GHGE-LU Scores of any regional consumption pattern by linear programming using local LCA databases. Aggregating food items in LCA studies into real and acceptable diets offers a more realistic view of consumption patterns and it seems imperative to maintain nutritional quality as part of the comparative basis (Heller et al., 2013).

Cultural acceptability has to do with local foods and local agricultural history. Earlier, Swedish (Livsmedelsverket, 2009) and Finnish governments (Steering Group, 2010) have put together committees to give policy advice on environmentally effective diets. In line with these recommendations, locally grown foods, foods from organic food production, and a proportion of the diet from foods sourced from the wild countryside, were included in the formulation of the NND (Mithril et al., 2012). Saxe et al. (2013) confirmed that the climate impact of the local, organic NND is lower than the average and recommended diets. Although the NND reduces the environmental impact relative to the current diet by reducing the content of meat and excluding most long-distance imports, it increases the impact by including high amounts of organic produce (Saxe, 2014). According to the LCAs performed by Sevenster et al. (2010) the impact of ammonia from fertilizer use is 3.1%, the impact of pesticides is 2.1%, and other impacts through emissions are 0.3% of the total environmental impact of food production in the Netherlands. More local production of fruits, vegetables and nuts will replace former production of feed, sugar beet and grasslands, which is expected to result in some changes in e.g. pesticide use, but these changes are likely to be small based on the percentages mentioned. In the linear programming dataset in this study no options for organic are included, but the results in Table 5.5 show a preference for local fruits, legumes and vegetables in the LLD.

In this study we have quantified the sustainability in a combined score of GHGE and LU. Chemical inputs and localness are included in the linear programming approach by GHGE from energy use for fertilizers and transport. The use of linear programming results in much higher Combined GHGE-LU Scores than calculated scores of diets such as MD, NND or Dutch recommendations. We demonstrate that neither the NND, nor the MD, are optimal in their Combined GHGE-LU Scores. The reason is a relative high amount of meat, fish, vegetables and fruits. The optimized LLD shows that with smaller quantities of these products a Health Score can be achieved on the same level as the MD. It is important to mention the common ground of the results for MD, NND and LLD. All diets consist of basic food products, which have a high nutrient density and most of the time a low energy density. Most of the volume is plant-based products, such as whole grains, fruits, vegetables, oils, pulses and nuts. All diets include animal products in moderate quantities.

The Health Score (van Dooren et al., 2014) covers ten health related nutritional characteristics. The associated formula (Eq. 1) contains three implicit assumptions. The first is linear effects of the various aspects, on the negative side as well as on the positive side. For fish, salt and saturated fat, linear effects are described (Health Council, 2006), but for others these are assumed. The second is that positive aspects can compensate less healthy aspects of a diet. Effect is calculated as risk factors. If the risks are affecting the same risk factor for a diet related disease, e.g. blood pressure, overweight or LDL cholesterol, risks can be compensated. This is not the case with all nutritional characteristics. From a health perspective, a score of 100 for each characteristic is ideal. A third assumption is the use of an equal weight of the ten aspects. Risk assessments (van Kreijl et al., 2006) state that five aspects are most relevant, but a quantified weight is not yet available. The Health Score could be improved in the future when there is a consensus on weights.

When interpreting the results, it is important to consider that the methodology used to score health and sustainability is based on a limited number of parameters. Other parameters, such as fossil energy use, water use, and ReCiPe-score were outside the scope of this study. The data are not based on dietary assessments, but on a general description from the literature about different diets. This results in some uncertainties. Combined GHGE-LU Scores are based on Dutch data on LCAs of common food products. Most of these products are familiar to Mediterranean and Nordic cuisine, but differences in transport and agricultural methods would result in slightly different estimates of GHGE and LU. Besides, the results reflect a hypothetical situation in which the NND or MD is adopted by the Low Lands. Because of the limited number of products (206) used in the calculations, no detailed results of the diets could be given. For instance, some traditional products were missing and replaced by comparable products (e.g. oats and barley by wheat). Furthermore, the study should not be interpreted as a retrospective study on the sustainability impact of the situation before 1940. Surely, energy intensity, processing and yields differ significantly over time. The calculation of the traditional LLD reflects the situation if male adults from our area were to eat as our ancestors and grandparents did 75 years ago, and a part of the population still does. Rather than trying out diets recommended in the literature, this case study confirms the usefulness of linear programming to improve existing and culturally relevant diets.

5.5 Conclusion

Through applying the method of linear programming, it was possible to calculate an optimal diet for the Low Lands, that is, as healthy as and more sustainable than the MD, or NND. This paper demonstrates that linear programming can facilitate the definition of nutritionally healthy, environmentally friendly and culturally acceptable diets, using the Low Lands as an illustrative example. An optimized Low Lands Diet has comparable nutritional characteristics to the Mediterranean and the Nordic Diets, but results in a lower environmental impact and a higher Combined GHGE-LU Score. All three diets, MD, NND and LLD, consist of basic food products, which have a high nutrient density and most of the time a low energy density. Most of the volume is plant-based products, such as whole grains, fruits, vegetables, oils, pulses and nuts. All diets include animal products in moderate quantities. The Health Score of the historical LLD is 106 and the Combined GHGE-LU Score of 103. They are comparable and close to the recommended guidelines, but the LLD Health Score is lower and the Combined GHGE-LU Score higher than those of the MD and NND. The optimization by linear programming placed the LLD scores in between the Health Scores of the MD and NND (123 versus 122 and 137), but resulted in the highest Combined GHGE-LU Score (121). GHGE are 2.60 kg CO_2eq per day and LU 2.86 m^2*year. These results are relevant because an adaptation of the historical diet, which fits better into the present eating habits, climate, and agricultural tradition of the Low Lands, is concluded to be easier to achieve than a transition to a more foreign Southern or Northern European diet, because there is a short cultural distance. This supports the hypothesis that linear programming can be used to develop diets optimized for sustainability, nutrition, and cultural acceptability more generally. The example of this study can be used to improve Health Scores and Combined GHGE-LU Scores of any regional consumption pattern by linear programming using local LCA databases.